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## Abstract

The cratering of sand under gas jets is observed to further understanding of soil in hopes to further understand lunar soil. Lunar soil is important to understand because it is causing problems with the materials taken into space including the shuttle. Lunar soil is not rounded like beach sand. Lunar soil is sharp like little particles of glass, and some times when blown they can hook on to one another and become bigger particles. The experiments are designed to help to understand some of the basic physics in how the shuttle jets will interact with lunar soil and how to control the lunar soil. These experiments investigate the diameter of the gas jet and the size of the sand grains to determine how these parameters affect the erosion rate and the cratering processes. Therefore, the experiments performed will point out what is dependent and what is independent.

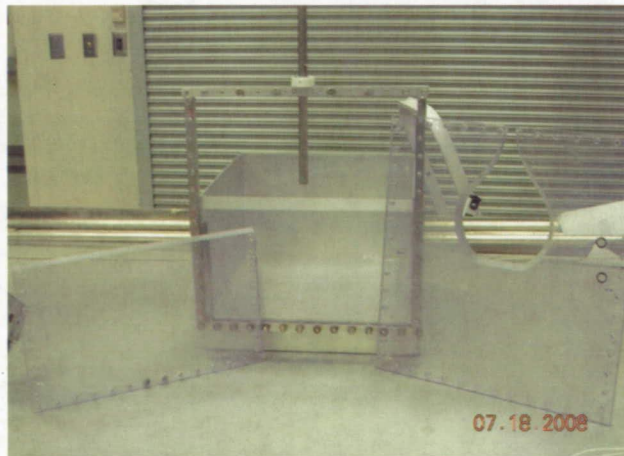
## Introduction

Over the summer, significant research was performed in regards to the excavation of sand by impinging jets of gas for lunar landings. The various experiments helped to unravel some basic physics principles relating to gas jets interactions with the soil. These investigations included researching the diameter of gas jets and the size of the sand grains to determine how these parameters affect the erosion rate and the cratering process.

Lunar soil plays a significant role in the landings. "Lunar soil is dusty; typically, over 95% is finer than 1 millimeter; about 50% is made of sand smaller than 60 micrometers (the thickness of a human hair); and 10-20% is finer than 20 microns. The lunar soil particle-size distribution is very broad... The soil is very poorly

sorted." (Need to reference the quotation) The sizes vary all through out but most of it is very little. Since lunar soil is limited there are different simulates and they all have their own different qualities that are like the original but not yet identical. Some simulates are magnetic and some are not.

NASA is facing a complex issue concerning lunar soil. It has been discovered that the soil found on other planets is different for the soil found on earth, due to things like the lack of atmosphere and lower gravity. The soil on other planets resembles tiny chips of glass that are very sharp and light. This causes complications with the shuttle, the space suites, and all things else we bring into out of space.



**Figure 1.**

Sand box with the three different faces. The face to the left has a 30 degree angle, the face on the box in the middle has a 60 degree angle, and the face on the right has a tear drop cut with a 60 degree angle.

During the research, materials were used to perform various experiments including pipes, a flow meter, a solenoid valve, a regulator, a long tray that extended from a box, and a box to hold the sand. The box was made out of three metal sides and the fourth side was made out of Plexiglas. The top of the Plexiglas was cut at a 60 degree angle to slice the gas flowing down in half, so that the sand that is being observed can get the full blast of the exact middle of the flow. The sand box had three different faces that can be changed for various experiments. The Tear Drop design was used to keep most of the sand inside the box while the flat top was used when more than one pipe was needed for the same experiment.



**Figure 2.**

The flow meter tells how much gas flows through the pipe per second.

A description of the devices is meaningful to help understand their need and purpose. A regulator is a device used to reduce the pressure of gas from a tank. A solenoid valve is an electromechanical valve which controls the running or stopping of liquids or gases as they pass through the solenoid. The solenoid itself is a coil of wire which changes the state of the valve and its operation is very similar to that of a switch for a light or fan, except the solenoid valve controls the flow of air or water instead of controlling the flow of electricity. The flow meter tells how much gas flows through the pipe per minute. To evaluate the readings from the flow meter a spreadsheet is used to convert it from standard liters per

minute to meters per second. The pipes consist of various sizes, which are needed to run different tests used to determine if the results would vary.

The simulate used for the cratering and erosion testing is JSC-1A. This material is hazardous and while working with this material certain precautions had to be taken. It was important to be especially careful handling the stimulant so that only a minimum dust would be released to the environment. Other necessary precaution involved the wearing of a respirator in which training was mandatory for its proper use. Research showed the stimulant to be odorless and is a dark gray color. Its melting point is 1100 -

1125 Degrees C. The Specific Gravity is 2.9g/cm<sup>3</sup> and it is not flammable. The angle of internal friction is 45 degrees. The stimulant contains grains that are under ten microns and that are what makes it so hazardous. In fact, anything that small can create a dust which that

Phi	Grade		Mm.	Microns
-8	Boulder	G		
		R	256	256,000
-6	Cobble	A	64	64,000
		V		
-2	Pebble	E	4	4,000
		L		
-1	Granule		2	2,000
0	Very Coarse		1	1,000
	Coarse	S	0.50	500
1		A		
	Medium	N	0.25	250
2		D		
	Fine		0.125	125
3	Very Fine			
			0.0625	62.5
4	Coarse			
			0.0313	31.3
5	Medium	S		
		I	0.0156	15.6
6	Fine	L		
		T	0.0078	7.8
7	Very Fine			
			0.0039	3.9*
8	Clay			

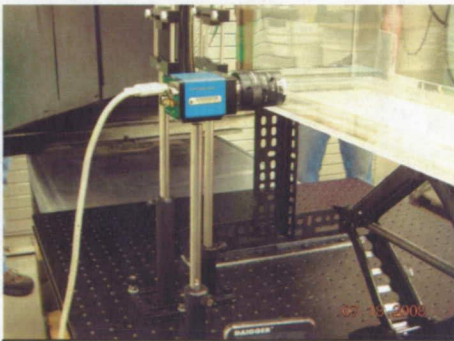
**Figure 3.**

Grain size chart

can flow with the air causing serious health problems for the human body, including a serious disease called Silicosis. Silicosis is a lung disease that is incurable and caused by inhaling dust containing free crystalline silica. This disease kills thousands of people each year could also cause a person to become disabled, both temporarily and permanently. Though the human body has many defenses, there are none to prevent a substance this small from entering into the body and attacking major organs.

The major elements of JSC-1A are Silicon Oxide ( $\text{SiO}_2$ ), Titanium Dioxide ( $\text{TiO}_2$ ), Aluminum Oxide ( $\text{Al}_2\text{O}_3$ ), Ferric Oxide ( $\text{Fe}_2\text{O}_3$ ), Iron Oxide ( $\text{FeO}$ ), Magnesium Oxide ( $\text{MgO}$ ), Calcium Oxide ( $\text{CaO}$ ), Sodium Oxide ( $\text{Na}_2\text{O}$ ), Potassium Oxide ( $\text{K}_2\text{O}$ ), Manganese Oxide ( $\text{MnO}$ ), Chromium oxide ( $\text{Cr}_2\text{O}_3$ ), and Diphosphorus Pentoxide ( $\text{P}_2\text{O}_5$ ). Too much exposure to the stimulant may cause harm to the body.

A test was conducted to determine the reaction of jet methods on lunar soils. It was revealed that very little space on the shuttle would be needed for this study however; the spacecraft would need to be in the air for best results. One thought was to spread gravel on top of the surface to create a landing area or to use a material other than gravel like a substance called palliative the Afghanistan military used. Additional research proved that the use of situ lunar regolith beans were successful in stabilization of the soil, but made good landing more difficult. A pre-blast with the rocket engines could clear the loose soil from the top layers and leave it bare to the hard regolith. Therefore, an inflatable deflector shield would be needed to protect the ship, and an inflatable landing pad would prevent the soil blowing every where.



**Figure 4.**

The high speed camera used to analyze the growth of the dimensions of the crater.

There is also the option of cutting off the engines early and landing on airbags or the use of tanks as a pad surface structure foundation along with the idea of landing in a bubble. This is where something will extend from the bottom sides and reach the ground. When the space craft gets close enough to the sand it is blown around and the bubble is used to trap the soil. There are still lots of engineers and scientists working on solutions related to protection of exposed equipment against lunar soil.

Through viewing many landings of the spacecrafts by computer of the way the lunar soil reactions, different things were calculated. For example, the different angles the soil sprayed up, the

distance each grain went, the way the scenery looked after all the soil settled, and how long it took the soil to settle. To properly calculate all the effects, software is used called Labview. This software allows data to Acquired, Analyzed, and Presented. Labview performs a wide variety of measurements which includes Temperature, Voltage, Resistance, Pressure, Strain, Current, Pulse, Force, Vibration, Frequency, Period, Sound, Light, Digital, and Signals, by gathering data and calculating it to give the answers needed. It is used in an open environment to make interfacing with hardware the measures easier to read. Labview can be connected to thousands of devices however, for these experiments it was connected to a Prosilica video camera. Labview has more than 600 built-in functions for signal synthesis, frequency analysis, probability, statistics,

math, curve fitting, interpolation, digital signal processing, and more. Using the proper function allows the data that has been analyzed can be put in a presentable state. The software was developed to automatically analyze the high resolution video frame-by-frame. It is used throughout the test duration to extract crater shapes and related parameters and to perform surface and volume integrals on the crater shape.

Before any tests were performed the sand had to be distributed into different sizes. To do this the sand had to be sieved. The analysis was then used quantify a sample of sand by determining its particle size distribution. The trays have a mesh screen on the bottom of them, and each tray has different size mesh spacing. The trays are stacked from the low numbers on the bottom and the high numbers on top. Once the trays are stacked they are placed on a machine that vibrates at a fixed period of time.



**Figure 5.**  
Screens used to perform a sand particle size distribution analysis.

During the different tests the density of the soil had to be checked along with the volume. To access the different densities of beach sand the following method was used.



**Figure 6.**  
The sand table completely set up without the gas.

The sand was placed in water and positioned it on a vibrating table to get all the air out. Then vibrations were used to separate the sand from the air before taking measurements, during the experiment a few things needed to be recorded: how much gas flows through the pipe per minute, how far the pipe is from the sand, how high the sand is in the box, what size sand is being used, what size pipe is being used, and how much pressure is being used. Once all of this is noted, the video camera records the remaining data that is needed. These experiments are used to discover what is dependent and independent to the parameters in the make-up of a crater.

Several tests have already been run by Carly M. Donahue, former NASA intern, by varying gas density times velocity squared and nozzle height in centimeters and nozzle inner diameter in centimeters, these test concluded that the gas density times velocity squared is independent and the nozzle height

is dependent. The results for the nozzle inner diameter was scattered and more test are needed to determine if it is dependent or independent. Preliminary results are still in progress.

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